



NASA Space Communication and  
Navigation Program

# Space and Earth Terminal Sizing for Future Mars Missions

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# Motivation for the Study

## Future Missions to Mars

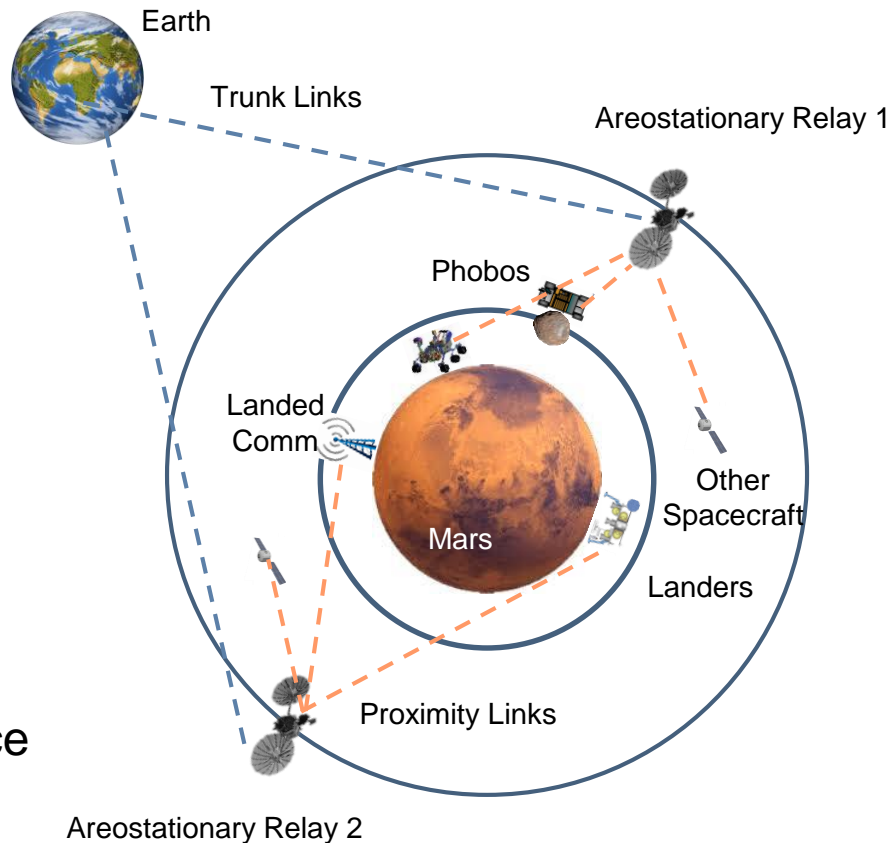
- The NASA Space Communication and Navigation (SCaN) program is investigating potential communications architectures to support future missions to Mars
  - Time horizon out to about 2040
- Explore options for providing sufficient capacity
  - Earth-, Earth-orbiting, Mars-orbiting, Mars-landed assets
  - Radio and Optical
- Compare relative strengths and weaknesses
  - Estimate the size, weight, power (SWaP) and comparative cost

# Drivers on Communications Capacity

- Forecasted need for dedicated relay orbiters at Mars starting around 2031, at Mars Areostationary altitude (17,000 km)
- A human spaceflight mission aligned with a 24-day Mars short-stay surface scenario
- A crewed Mission to Phobos
- A collection of Mars orbiters and landers that would rely on a mix of radio frequency and optical communication
- SCA's planned RF ground asset capacity for 2016-2040
- Possibility of an Earth-based optical subnet with global coverage, and an Earth orbiter carrying a substantial optical telescope for communication purposes

# Structure of the Study

- Architectural Tenets
  - 1. Meet trunk data rate goals
  - 2. Minimize user burden
  - 3. Observe constraints of spectrum and components
  - 4. Minimize total system cost
- Study conducted in two passes
  - Pass 1 to compare the feasibility of link types for maximum user needs
  - Pass 2 considering feasibility, reduce requirements to be affordable, especially Earth terminals



# Communication Requirements

Topic	First-pass requirement	Second-pass requirement
Trunk Link Topology	1: X forward, X/Ka return 2: X forward, X/Ka/optical return	Ka-band forward RF/optical return: X/Ka-optical
Trunk Link Data Rate	50/250 Mbps forward/return X-band unconstrained	30 Mbps forward 50, 75, 125 Mbps return
Proximity Link Topology	1: UHF/X forward/return 2: UHF Forward/Return optical return 3: UHF/X/Optical forward/ return	Ka-band forward and return Optical forward and return
Proximity Link Data Rate	50 Mbps forward/return UHF unconstrained	0.5, 10, 50, 100 Mbps forward and return
Optical Earth Terminal Type	12-meter monolithic 8-meter monolithic 8-meter optical/RF hybrid 4-meter optical array	8-meter optical/RF hybrid
Radio Earth Terminal Type	Deep Space Network 34m Beam Waveguide Antenna	Same
Mars Relay Location	Areostationary	Same
Mars Surface Element Location	Equatorial spot region, lat/long limit for elevation >45 deg to Areostationary relay	Same

# Estimated SWaP and Comparative Cost for RF Terminals

Terminal	Volume l *	Mass kg	Power W	Normalized Cost Units Nth Unit **	Normalized Cost Units 1st Unit
X/X/Ka Areostat Trunk 50/75 Mbps	57,012	66.4	1011	116.6	198.0
X/X/Ka Areostat Trunk 125 Mbps	57,015	71.8	1891	124.8	225.1
Ka Prox Areostat 100 Mbps	105	7.7	94	29.3	46.7
Ka Prox Areostat 50 Mbps	105	6.1	49	23.9	33.1
Ka Prox Areostat 10 Mbps	102	2.8	9.5	5.4	11.9
Ka Prox Areostat 0.5 Mbps	101	2.5	2.5	3.8	9.3
Ka Prox Surface 100 Mbps	31	6.9	94	26.8	41.9
Ka Prox Surface 50 Mbps	31	5.3	49	21.3	28.3
Ka Prox Surface 10 Mbps	28	2	9.5	2.9	7.2
Ka Prox Surface 0.5 Mbps	27	1.7	2.5	1.3	4.5

\* Deployed volume, launch volume may be less      \*\* Cost scaled by an arbitrary factor

# Est. SWaP and Comparative Cost - Optical Terminals

	Prox Surface				Prox Areostationary					Trunk						
Transmit	1.2 mW	25 mW	0.2W	0.5 W	1.2 mW	25 mW	0.2W	0.5 W	2W	4W	16W	23W	3x15W			
Aperture	5	5	5	5	10	10	10	10	10	22	50	50	50	cm		
Volume																
Total	1.1	1.1	1.1	1.1	9.0	9.0	9.0	9.0	9.0	96	456	456	456			
Mass																
Total	4.3	4.3	4.3	4.4	11.2	11.2	11.2	11.3	11.6	37.7	142.6	142.6	142.6			
Power																
Total	26.5	26.6	27.2	28.3	26.5	26.6	27.2	28.3	33.6	40.7	186.5	256.5	476.5			
Cost				20					24	38	94	94	94	cost	Theory 1	
				10					15	38	129	129	129		Theory 2	
				4					8	38	313	313	313		Theory 3	

## Cost Scaling Laws:

Theory 1: Stahl et al<sup>4</sup> 2004  $D^{1.7}$  OTA

Theory 2: 50% fixed + 50% Meinel et al<sup>5</sup> 2004  $D^{2.7}$  Observatory

Theory 3: 20% fixed + 80% Meinel et al<sup>5</sup> 2004  $D^{2.7}$  Observatory

# Observations 1

- Optical, Ka-band, and X-band are all feasible
  - However, for a purely radio system, the Areostationary terminals would be quite large when fully deployed (~57,000 L)
    - Launch configuration is unknown at this stage, but volume could be much less if antenna were to be folded
- The UHF data rate for proximity links can be adjusted from a rate achievable with familiar low gain orbiter UHF antennas (10 kbps) up to 360 kbps using very large antennas
  - Multiple simultaneous proximity links would need multi-beam phased arrays, and even then might be impractical from a size viewpoint
  - This was a driver to consider X-band, Ka-band, and optical for proximity links.

## Observations 2

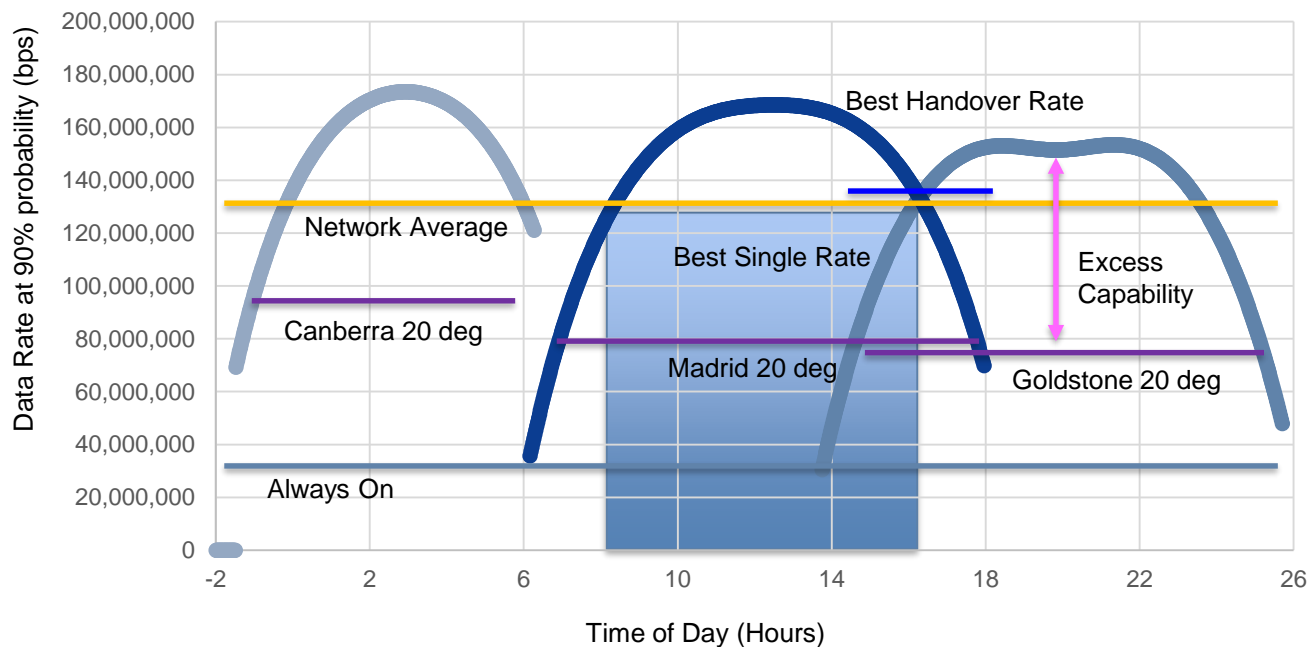
- X-band can close the proximity links at 50 Mbps
  - But the Areostationary terminal would require fine pointing, not the current practice of staring at the planet with a broad beam
  - The full X-band spectrum allocation would be needed to handle the required data rate for a single user
- Optical solutions provide substantial size advantages
  - Mixed advantages/disadvantages on mass and power
  - Optical could solve spectrum issues
  - Multiple heads could serve many users in less volume than RF

## Observations 3

- In the first pass through the study, we found large costs associated with Earth terminals, both for radio and optical
  - Total system cost could be lowered substantially by increasing the size and cost of the spacecraft relay trunk link elements
- We noticed substantial effects of elevation assumptions in the RF Earth terminal analysis (see next page)

## Impact of Elevation Assumptions on RF System Capacity

- Issue: Select from among multiple potential interpretations of link capability – implications for system cost and risk on the order of 2-3 dB





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